Synopsis of the Flora and Vegetation of Oman, with Special Emphasis on Patterns of Plant Endemism*

Annette Patzelt

Oman Botanic Garden, Diwan of Royal Court, P.O. Box 808,
Muscat 122, Sultanate of Oman

1. Introduction

The Sultanate of Oman in the southern Arabian Peninsula is mainly characterised by arid habitats, with much of the region occupied by sand dunes or rock and gravel desert. However, and often in stark contrast to the deserts, the country also contains a seasonal cloud forest, open juniper woodlands and other habitats supporting high species diversity with many endemic plants.

Oman lies in the transition zone between the Holarctic and Palaeotropical kingdoms, as well as between subtropical and tropical climate zones (Fig. 1). This position is reflected by the presence of plant species from several biogeographical regions (Miller & Nyberg 1991; Kürschner 1998) as demonstrated by the comparatively high number of vascular plants in Oman (1239 species) (Patzelt et al. 2014).

A period of intensified botanical research in Oman has taken place over the last two decades (Miller & Cope 1996; Ghazanfar & Fisher 1998; Ghazanfar 2003 & 2007; Cope 2007; Feulner 2011; Patzelt et al. 2014; Patzelt in press a). There has been good progress extending our knowledge of the flora of Oman, resulting in the description of 103 new range-restricted species since 1980 and the documentation of new records for the country (Patzelt et al. 2014; Patzelt in press. a). However, detailed studies of the vegetation and plant communities are still scarce and current knowledge ranges from no documentation at all to brief descriptions of the vegetation types or to characterisation of the vegetation units by their complete floristic composition and arranged in a hierarchical system of floristic similarity. Data are also lacking regarding the population parameters and ecology of individual plant species.

Oman has a total of 191 range-restricted species, representing 13.6% of the total flora. This high proportion of range-restricted species (endemics, near endemics and regional endemics) in the Sultanate can be explained by a unique combination of ecological factors that restricted the range of species in the past. Endemics are

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found in all vegetation types throughout the country. However, some habitats are particularly rich in range-restricted species and are of special interest, encompassing sites of maximum biodiversity. Significant species-rich habitats include the monsoon-affected mountains in southern Oman, the northern Hajar mountains, and the coastal areas of the central desert; these areas represent local centres of plant endemism.

The first aim of this publication is to present comprehensive information about the flora and patterns of plant endemism in Oman. Secondly, an overview of the main vegetation types and land units in Oman is presented. Conservation issues and concerns are raised throughout the document.

The taxonomic treatment by The Plant List (2013) was followed, Version 1.1., (http://www.theplantlist.org/). Family assignations of the vascular plants follow the Angiosperm Phylogeny Group (Angiosperm Phylogeny Group 2009). All conservation assessments are based on IUCN Red List criteria version 3.1.

2. Phytogeography

Plate tectonics and climate both recent and historic – have greatly influenced the migration and evolution of plants and plant communities that exist today. Oman's position at the intersection of several biogeographic regions coupled with the diversity of geology, topography, and climate conditions, have resulted in a rich flora with a high degree of endemism.

As a result of Oman's geographic location plant species from several bio-geographical regions are present (Leonard 1989; White & Leonard 1991). These regions include the Saharo-Sinian region and the Nubo-Sindian centre of endemism as part of it; the Somali-Masai centre of endemism (mainly in southern Oman); and Irano-Turanian regional centre (in northern Oman). The Nubo-Sindian centre of endemism is represented in Oman by the omano-macranian subprovince. More detailed plant geographical divisions are given by Kürschner (1986) and Leonard (1989).

The gradient from extratropical to the subtropical climate and the transition from the holartic to the palaeatropic kingdom are expressed differently throughout the country in the various vegetation types and steep floristic gradients that occur. The flora is enhanced by remarkable endemic plant species that are often very restricted in distribution.

3. Endemic Species in Oman

1239 species of vascular plants and ferns from the Sultanate of Oman have been documented (Patzelt et al. 2014). Recent research by the author indicates that

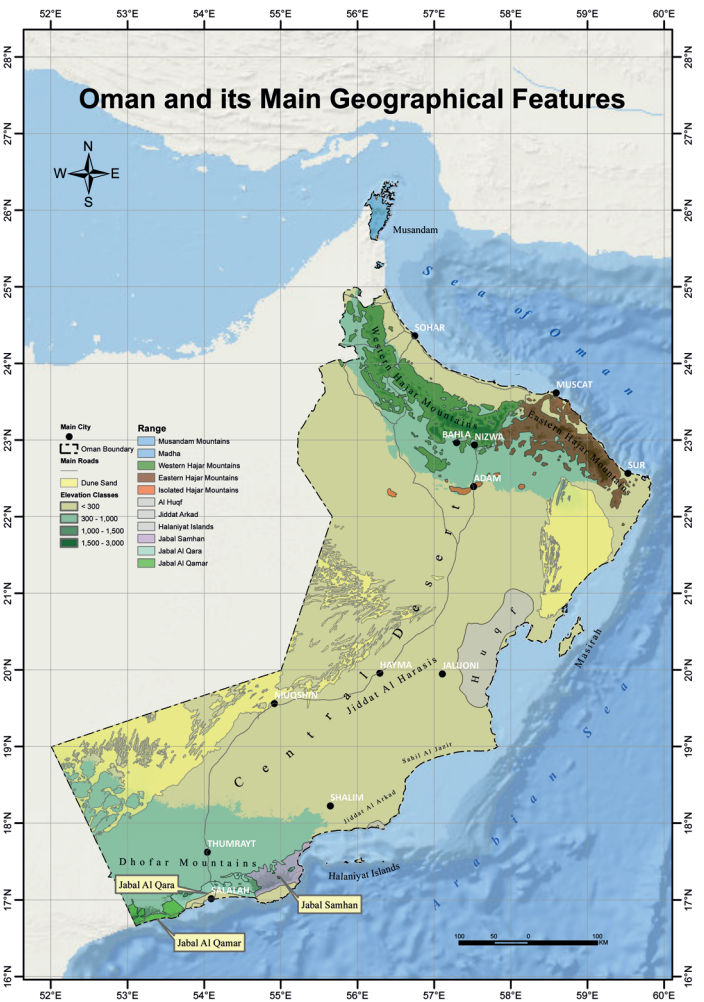

Fig. 1: Map of the Sultanate of Oman.

this number is higher and is estimated to include 1407 taxa (Table 1); a detailed checklist is currently in preparation. The number of 1407 species compares regionally to a flora of 2100 species in Saudi Arabia, 1650 species in Yemen (N), 1180 in Yemen (S) and 825 on Soqotra (Miller & Cope 1996; Miller & Morris 2004). The remaining other countries on the Arabian Peninsula (UAE, Qatar, Bahrain and Kuwait) have considerably lower numbers of plant species (Miller & Cope 1996).

Table 1: Floristic Analysis of Oman.

	Families	Genera	Species
Pteridophyta and fern allies	6	12	17
Gymnospermae	2	2	4
Angiospermae:			
Magnoliids	3	3	3
Monocotyledonae	18	139	319
Dicotyledonae	84	487	1064

At present 51% of the total flora (at least 716 species) are found in northern Oman, 254 species are found in Central Oman (representing 18% of the total flora), and 817 species are found in southern Oman (representing 58% of the total flora). These data represent the current stage of knowledge; further field-based research can be expected to increase these numbers.

Oman has a high percentage of endemics, with 191 taxa that are range-restricted, representing 13.6% of the total flora of the country. 77 plant species are strictly endemic to Oman (including 13 species new to science), 53 species are near endemic (species occurring in one geographical entity, but in two countries), and 61 species are regional endemic to the Arabian Peninsula (occurring in at least two different countries and in more than one geographical entity). An additional 68 species are considered to be threatened but not range-restricted (Fig. 2; updated from Patzelt in press. a). The high proportion of range-restricted species in Oman can be explained by allopatric speciation events and a unique combination of ecological factors that restricted the range of species in the past.

Previous analyses have significantly under estimated the number of range-restricted species in the Sultanate of Oman. The new figure of 191 range-restricted species compares to much lower species numbers listed in earlier publications: 60 in 1991 (Miller & Nyberg 1991; White & Leonard 1991), 73 listed in 1994 (Heywood & Davis 1994), 75 in 1996 (Miller & Cope 1996) and 94 in 1998 (Ghazanfar 1998). With 191 species now known as being range-restricted, the percentage of range-restricted species in the country rises from an estimated 5% in 1991 (Miller & Nyberg 1991) and 7% estimated in 1996 (Miller & Cope1996) to 13.5% of the total flora.

Range-restricted species are not distributed randomly over the country, but concentrate in three areas recognised as local centres of endemism (Miller & Nyberg 1991; White & Leonard 1991; Patzelt in press. a):

1. The monsoon-affected mountains of Jabal Al Qamar and Jabal Al Qara (southern Oman)

2. The dry high plateau and wadi systems of Jabal Samhan (southern Oman)
3. The limestone plateau and coastal escarpment the Jiddat Al Harasis/Huqf (central Oman)

Recent research indicates that the dry Jabal Samhan (southern Oman), as well as the Jiddat Al Arkad/ Sahil Al Jazir (central Oman) deserve to be treated as a separate floristic units, thus increasing the number of local centres of endemism to five:

4. The limestone plateau and coastal escarpment of the Jiddat Al Arkad/Sahil Al Jazir (central Oman)
5. The mountains of northern Oman (including the Musandam mountains)

The mountains of northern and southern Oman contain comparable levels of species diversity and endemism. This differs in the Central Desert, which has low species diversity, but a comparatively high number of range-restricted species (Table 2).

Table 2: Regional concentration of endemic and threatened non-endemic species in the five centres of local plant endemism (END = Endemic; Near END = Near Endemic; REN = Regional Endemic).

Region	Total nr. of species	END	Near END	REN
Jabal Al Qamar and Jabal Al Qara	660	32	46	35
Jabal Samhan	377	23	33	22
Jiddat Al Harasis/Huqf	222	13	3	20
Sahil Al Jazir/Jiddat Al Arkad	133	13	4	13
Mountains N Oman	703	24	6	28

To analyse the distribution patterns along an altitudinal gradient, the altitudinal distribution ranges have been determined separately for all range-restricted and threatened species. The analysis has been carried out based on defined altitudinal zones with a height of 100 m (Fig. 3).

The data reveal the high importance of the lower altitudes for the range-restricted and threatened species. The altitudinal distribution of species shows a high concentration of these species in lower and medium altitudes. With increasing elevation, the number of range-restricted species decreases. The relative proportion of threatened non-endemic species gradually increases with altitude. The greatest portion of Oman's range-restricted and threatened flora is clearly found primarily in lowland and mid-altitude habitats up to the montane zone.

Range-restricted species are not equally distributed throughout the families (Fig. 4). Thirteen families out of the total of 113 families contain 128 species, repre-

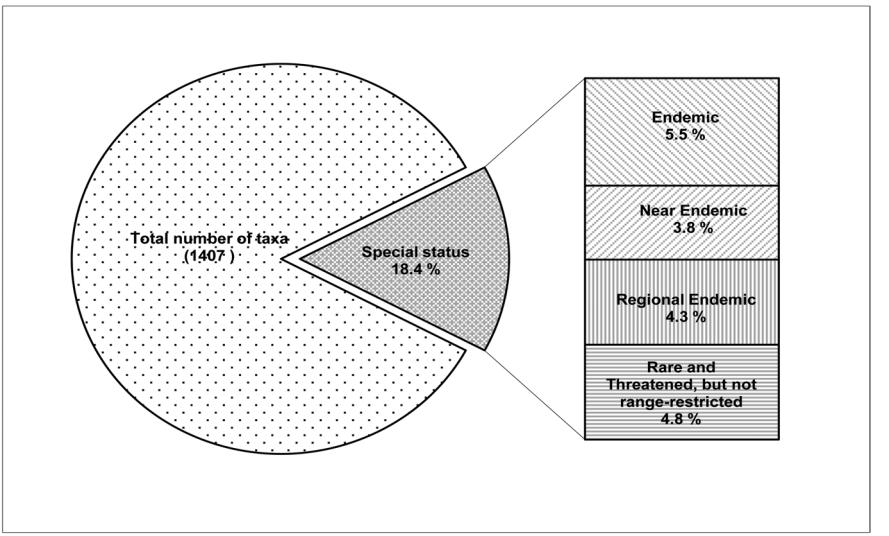

Fig. 2. Proportion of species with special status compared to the total number of plant species.

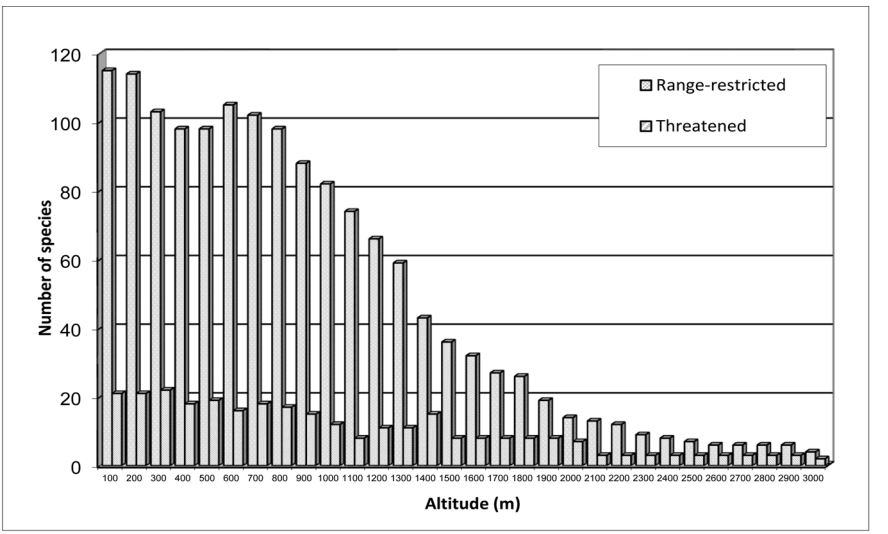

Fig. 3. Altitudinal zonation of range-restricted and threatened non-endemic species.

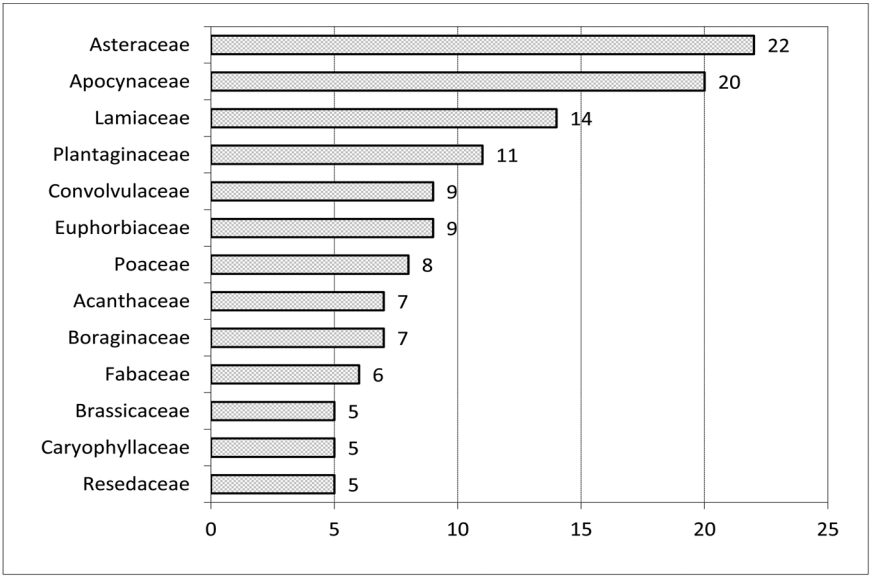

Fig. 4. Families with the highest representation of range-restricted species.

senting 64% of all range-restricted species. The plant families with the highest number of range-restricted species are Asteraceae (22 species), Apocynaceae (20), Lamiaceae (14), Plantaginaceae (11), Euphorbiaceae and Convolvulaceae (9), Poaceae (8), Acanthaceae and Boraginaceae (7), Fabaceae (6), and Brassicaceae, Caryophyllaceae and Resedaceae (5).

The largest families of the total flora in the country are Poaceae (223 species), Fabaceae (127), Asteraceae (114), Malvaceae (54), Amaranthaceae and Boraginaceae (49), Euphorbiaceae (34), Plantaginaceae (31), and Scrophulariaceae (15). Thus, it is not necessarily the case that large families also contain many range-restricted species. For some families, e.g. Poaceae, Fabaceae and Amaranthaceae, the percentage of range-restricted species is much lower than their relative proportion in the flora. The Malvaceae family, represented by 54 species, does not even include a single range-restricted species in Oman.

The majority of Oman's range-restricted species are found in the five centres of local endemism (Fig. 5). The lowland and mid-altitude mountains provide a rich variety of ecological niches while providing more stable and humid conditions during periods of drought. Under these more mesic conditions relict palaeo-African and palaeo-Indo-Malasian elements survived during a series of major fluctuations during the Pleistocene (Mandaville 1984 & 1986). The northern and southern mountains, isolated from each other by areas of inhospitable desert provided

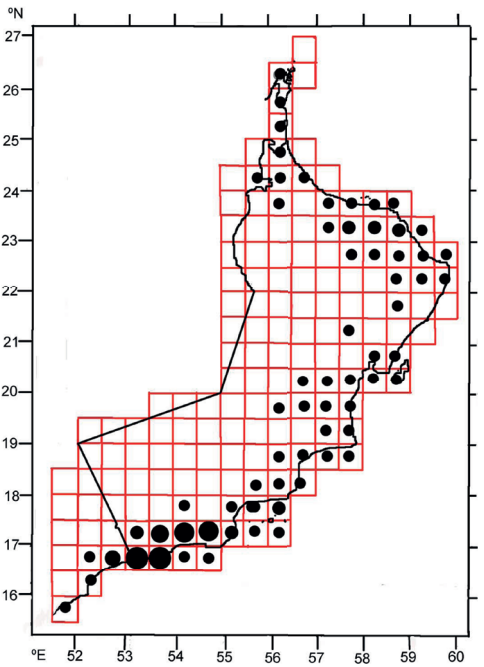

Fig. 5: Distribution of endemic and near-endemic species in Oman.

ideal sites for vicariant speciation. This process is obvious in many genera whose species show similar patterns of distribution and endemism, e.g. *Campylanthus, Lavandula, Pulicaria, Pycnocycla, Schweinfurthia, Taverniera* and *Teucrium* (Miller & Nyberg 1991).

The reasons for the high number of range-restricted species in the relatively low coastal areas of the central deserts may be a function of the ecological niches provided by the escarpments and the wadi systems. The influence of occasional fogs provides a relatively stable supply of moisture and may also contribute to the high number of range-restricted species in the central deserts. A better understanding of the present and past climate conditions and species distribution might help us understand the present day species diversity in these areas.

4. The Main Landscape Units and their Vegetation

The vegetation zones can be described on the basis of their floristic composition, in association with varying altitude and environmental factors, such as climate

and substrate. The vegetation of Oman in most areas has not been studied systematically; this contribution allows a first overview of most main vegetation types, as a prerequisite for further ecological and phytogeographical studies. The gaps of knowledge on flora and vegetation need to be filled through comprehensive field-based research. Work to describe, classify and rank the plant communities of Oman is on-going.

I. The Coastal Vegetation

Oman's coast is fringed by white dunes, occasionally coastal sabkhas (salt deserts), coastal lagoons, gravelly plains and rocky outcrops. Plants growing in coastal areas can tolerate salt, and many of them are obligate halophytes. The number of species is often low, with monospecific stands commonly occurring. Predominant species are members of the Sea-lavender (Plumbaginaceae) and Pigweed Families (Amaranthaceae) and of the grass and rush families (Poaceae and Juncaceae). Coastal areas are increasingly under threat by development and urbanisation.

A. Mangrove forests

Mangrove forests with pure stands of *Avicennia marina* occur in a number of scattered estuaries along the coast. This tropical vegetation type is characteristic of the tidal zone, muddy inlets and estuaries, and shallow lagoons which are either permanently flooded or over-flooded at high tide. This community represents the northernmost outlier of the paleotropical mangrove community.

B. Coastal plant communities

Coastal vegetation varies depending on local edaphic conditions. Four main relief elements are present: (1) low sandy dunes, (2) flat, silty-saline depressions (coastal sabkhas), (3) estuaries and coastal marshes and (4) cliffs and littoral rocky outcrops. The different elements often form a fine-grained mosaic.

A community characterised by *Tetraena quatarense, Halopyrum mucronatum* and *Sphaerocomum aucheri* is common in the coastal dunes. The nubo-sindian *Halopeplis perfoliata* is found in interdune silty depressions. Coastal sabkhas are characterised by the Oman endemics *Limonium sarcophyllum* and *Suaeda moschata*. The vegetation on coastal cliffs and littoral rocky outcrops is in most cases an impoverished version of the adjacent contact vegetation, augmented by halophytic species.

II. The Inland Salt Deserts (Sabkha)

The saline inland sabkhas are an extreme environment; the temperatures in summer reach above >50°C, the range of diurnal temperatures up to 33°C. The

sabkhas are characterised by soil crusts of salt and gypsum, and associations of cyanobacteria, archaea and algae over a black reducing layer. Rains occur during infrequent but torrential downpours, creating temporary lakes in inland depressions. The lakes evaporate and eventually precipitate salt at and just below the surface. These salt crusts can be up to several meters thick; they are irregular and the locally treacherous surface poses great difficulties for exploration. High Electrical Conductivity (EC) values reaching up to c. 9000 μS inhibit the growth of any vascular plants in the centre, where vascular plant life is virtually absent. At the fringes, EC values decrease and allow scarce growth of vascular plants, including the halophytes *Aeluropus lagopoides*, *Suaeda aegyptiaca*, and *Salsola drummondii*.

III. The Sand Deserts

Oman has two large inland sand deserts which cover huge areas: the Eastern Sands (Sharqiyah Sands; an isolated sand desert in the NE of Oman) and the Empty Quarter (Al Rub Al Khali). In the Eastern Sands, longitudinal dune ridges of eolian orange-red sand up to 100 m in height are formed and are separated by interdune valleys with gravel. Lower barchans are more or less consolidated. In the Empty Quarter, huge mobile barchans and massive stellate dunes bright golden-red in colour are found, which reach heights of more than 65 m. Precipitation is very low and may only reach c. 50 mm in the Eastern Sands and 15 to 35 mm in the Empty Quarter; some areas go without rain for years (Mandaville 1986). There is considerable marine influence on the Eastern Sands, particularly from winds bringing moisture from the sea in the winter months and in summer during the southwest monsoon.

Habitat variability is denoted by the different grain sizes and mobility of the sand, the amount of run-off water in the dune valleys and by grazing intensity. The flora is characterised by widespread saharo-arabian species, extending from the sand deserts in North Africa to the Arabian Peninsula and India. The vegetation forms a mosaic of communities, with typically very open but evenly distributed vegetation. Woodlands are absent except for a few stands of *Prosopis cineraria* woodland along the margins. Species richness is relatively low. Within the sand dune ecosystem at least three different habitats are distinguished: the dune valleys, the low dunes and the high dunes (Mandaville 1998).

IV. The Plains, Pediments and Coastal Escarpments

The plains, pediments and coastal escarpments comprise very different habitats including alluvial gravel plains, karstic limestones and dolomites, superposed masses of cretaceous ophiolite outcrops (crystalline rocks formed in the mantle

layer of the earth; found in northern Oman) and coastal escarpments of 50–100 m (in the central desert). All units contain rather broad wadi systems; both species richness and plant cover tends to increase in depressions, shallow runnels and other low-lying area.

In general, the plains, pediments and coastal escarpments lie within areas of low precipitation, usually with less than 100 mm/y and very high daily temperatures.

The central desert inner plateau is characterised by episodic rain events; the coastal areas are strongly influenced by two fog seasons and almost year round cool wind helps to keep temperatures down. Fog is the most reliable source of water for the central desert, and plays a fundamental role in supporting plant life. The fogs are caused by moist onshore winds which condense because of low desert temperatures at night. The fog distribution on the plains depends on distance to the sea and is reflected in the distribution, type and abundance of the vegetation. Further inland, in areas not reached by the cool winds, temperatures in summer are above 50°C, with a range of diurnal temperatures up to 33°C. Soil cover is usually shallow and overlain with a thin layer of gravel, large and small rocks, pebbles and sand.

The central desert has two dominant escarpments, the Huqf escarpment and the Jiddat Al Arkad escarpment. These two escarpments together with the adjacent plains exhibit distinctive climatic conditions and represent national centres of plant endemism. 222 species have been recorded from the Jiddat Al Harasis/ Huqf, including 11 endemics, 3 near endemics and 20 regional endemics; range-restricted species comprise c. 15.3% of the regional flora. At least 133 species are present in the Jiddat Al Arkad/Sahil Al Jazir, including 13 endemics, 4 near endemics and 13 regional endemics; range-restricted species comprise c. 25% of the regional flora.

The various plains, pediments and coastal escarpments of Oman fall under differing climatic, edaphic and biogeographic influences that are expressed in regional differences in the species composition and vegetation. The pediments in northern and southern Oman form the transition from the alluvial plain to the mountains, whereas the escarpments of the central desert abruptly separate the coastal plains from the inland gravel plateaus.

Several saltdomes are also part of the central desert and form distinct features on an otherwise featureless surface. They are devoid of plant life.

A. Open drought-deciduous *Euphorbia larica-Acacia tortilis* woodland (northern Oman; 0–450 m)

The plains and lower foothills are characterised by a combination of a subtropical temperature regime and winter rains. The flora is strongly influenced by the Saharo-Sindian phytochorion and the mean average temperature is 28.4°**C** with

an average of annual rainfall of 59 mm. This open drought-deciduous xeromorphic woodland community is characterised by the trees *Acacia tortilis*, *Ziziphus spina-christi*, *Prosopis cineraria* and *Maerua crassifolia*. The open woodland is also characterised by the presence of annuals and grasses that emerge after the January rains. Species diversity is high, with at least 211 species (c. 15% of the total flora). Typical perennial species are *Euphorbia larica* and the regional endemic *Pulicaria glutinosa* subsp. *glutinosa*.

B. Rocky slopes and coastal terraces with open xeromorphic *Commiphora myrrha-Euphorbia larica* shrubland (northern Oman on limestone; 0–500 m)

This *Commiphora myrrha-Euphorbia larica* community is found on bare limestone rock (FREY & KÜRSCHNER 1986). *Commiphora wightii* is usually more common than *C. myrrha*; *Plocama calycoptera* and *P. hymenostephana* are other commonly associated shrubs. Species diversity is high with at least 120 species found in this community (8.5% of the total flora of the country).

C. Rocky slopes and rock outcrops with *Fagonia paulayana* and *Plocama aucheri* (northern Oman on ophiolite; 0–450 m)

The ophiolite rock found in this region creates very distinct soils. The soils are deficient in calcium, nitrogen and phosphorus and usually rich in magnesium, iron and heavy metals such as cobalt, nickel and chromium, causing toxic effects on plants. Plant communities are distinctly different from nearby areas on limestone, and the ophiolite areas contain markedly less plant species than the limestone areas. Species diversity is much lower than on the adjacent limestone.

D. *Acacia tortilis-Prosopis cineraria* open woodland of plains, plateaus and hills of the Jiddat Al Harasis and Al Huqf (central Oman; 0–250 m)

While the central desert is low in plant species numbers, the percentage of endemic, near endemic and regional endemic species is very high. The vegetation on the plains and plateaus consists of sparse open thorn woodlands with *Acacia tortilis* and *Prospopis cineraria*. Common species in the grass and herb layer are the endemic shrubs *Convolvulus oppositifolius* and *Ochradenus harsusiticus*, and the endemic grass *Stipagrostis sokotrana*.

E. Xeromorphic dwarf shrubland with *Heliotropium bacciferum* and *Campylanthus sedoides* (central Oman; 50–150 m)

The plateau gravel desert is an extreme environment; the perpetual winds have removed much of the fine sediments and the surface is strewn with gravel and pebbles. Typical vegetation consists of very open xeromorphic dwarf shrubland intermixed with grasses and annual. A total of 95 plant species were recorded from the coastal escarpments and the adjacent plains (Eich 2005). In sandy depressions

adjacent to the escarpments the dwarf palm (*Nannorrhops ritchieana*) and *Acacia ehrenbergiana* are common species.

F. Xeromorphic dwarf shrubland with *Rhus ghallagheri* and *Ochradenus harsusiticus* (central Oman; 0–250 m)

Very few trees and large shrubs are present on the undulating plateau with its incised wadi systems of the Jiddat Al Arkad and the Sahil Al Jazir plateau and escarpment. The habitats appear to be low in plant diversity, however no detailed research has been conducted due to the remote location.

Due to the presence of several local endemics, it is strongly suspected that the environmental conditions differ to those of the Jiddat Al Harasis/Huqf plateau and escarpment area further north. It is assumed that this section of the central desert may be at the fringe of the monsoon-affected area, thus benefiting from occasional low clouds and cool winds during the south-west monsoon.

Plant endemism in this area is particularly high; endemic species restricted to this area include *Hyoscyamus gallagheri, Pulicaria pulvinata*, *Rhus ghallagheri*, *Polycarpaea jazirensis* and *Salvia* sp. nov. aff. *hillcoatiae*. Other endemic species with a slightly extended area of distribution are *Aerva artemisioides* subsp. *batharitica* and *Ochradenus harsusiticus*. The presence of these plant species supports the hypothesis that the area forms a distinct floristic unit.

V. The Hajar Mountains in Northern Oman

The Hajar mountains of northern Oman are part of an arid subtropical mountain system extending from southern Arabia to southwest Asia. In Oman, the northern mountain system includes the Western Hajar (highest peak 3006 m), Eastern Hajar (ca. 2000 m) and Musandam mountains (2008 m). The Hajar mountains consist of vast tilted massifs of highly permeable mid-Permian to mid-Cretaceous limestone, sandstone and dolomite. Ophiolite sequences are found at lower elevation in the Western and Eastern Hajar. Major wadi systems carve deeply incised canyons through the mountains, up to several hundred meters deep.

The climatic conditions of the Hajar mountains are arid to semi-arid, with a potential evapotranspiration of more than 2000 mm year (Nagieb et al. 2004). Mean annual precipitation rarely exceeds 400 mm in the Western Hajar, with rainfall concentrated in the early spring and late summer. This exemplifies the climatic transition of the study area from subtropical summer rain to extratropical winter rain. The Eastern Hajar and Musandam are marked by very low rainfall, estimated to be around 160–200 mm; detailed climate data for the Eastern Hajar and Musandam are scarce. Run-off from the slopes is considerable and permanent

surface water is very scarce. Soils generally are shallow and contain low levels of organic matter.

The natural vegetation of the Hajar mountains consists of open xeromorphic woodlands, deciduous and semi-evergreen shrublands, and grasslands. 394 species have been recorded to date from Musandam (Oman territory only), 485 from the Western Hajar and 324 from the Eastern Hajar.

The entire northern mountains are recognised as a centre of national and regional floristic richness (Miller & Nyberg 1991; Patzelt in press. a) and support a surprisingly rich and varied flora. The extent of the mountain uplift as well as the fragmentation and isolation from neighbouring mountain ranges has resulted in high levels of endemism: at least 24 species are strictly endemic to the Hajar Mountains, including *Dionysia mira*, *Teucrium mascatense*, *Campylanthus hajarensis,* and *Ziziphus hajarensis.*

The vegetation zones are different for the three mountain ranges. The distinct flora and vegetation of the Eastern Hajar as well as of Musandam has often been inadequately included in botanical descriptions of the Western Hajar, but recent and on-going research highlights the distinctive botanical character of these two mountain ranges that is distinct from the adjacent Western Hajar.

Isolation and separation from each other have resulted in significant differences in vegetation between the three mountain systems. Comparing the presence or absence of the key tree and shrub species of all three mountain ranges shows a clear reflection of the different climate conditions (Table 3).

In general, there is a close relationship between the high altitude flora and vegetation of the Musandam mountains and the Eastern Hajar mountains. The vegetation is characterised by species which are restricted to these two mountains systems within Oman, but which also occur in the desert steppe of high inner plateau of central Iran. The northern mountain vegetation in Oman clearly indicates a former pre-Pleistocene migration of Irano-Turanian elements into Arabia, and the current vegetation in Oman is interpreted as the southernmost outlier of the Irano-Turanian vegetation.

Similarities between the Iranian inner plateau desert and woodland steppe and the Western Hajar mountains are far less pronounced. The Western Hajar mountains receive considerably more precipitation thus supporting a more mesic vegetation. The desert steppe and woodland steppe of the inner Irano-Turanian deserts are represented in the more arid Eastern Hajar and Musandam mountains.

In addition to the natural vegetation, human-made terraces in spring-fed oases have existed in the mountains for centuries or millennia. A wide variety of crops has been and still is cultivated on these terraces in traditional, mainly subsistence-style oasis systems of remarkable beauty and interest.

Table 3: Absence or presence of key perennial species in the three mountain systems within the Hajar mountain range.

	Musandam	Western Hajar	Eastern Hajar
Trees/large shrubs			
Prunus arabica	key species	very rare	key species
Ziziphus hajarensis	absent	key species	key species
Ceratonia oreothauma	absent	absent	key species
Olea europaea subsp. *cuspidata*	absent	key species	rare
Acacia gerrardii subsp. *negevensis*	absent	key species	key species
Sideroxylon mascatense	absent	key species	rare
Juniperus seravschanica	absent	key species	absent
Perennial shrubs			
Astragalus fasciculifolius	key species	absent	rare
Artemisia sieberi	key species	absent	absent
Convolvulus acanthocladus	key species	very rare	key species
Ephedra pachyclada	key species	key species	key species
Sageretia thea	absent	key species	frequent
Ebenus stellata	absent	key species	key species
Daphne mucronata	absent	key species	key species
Lonicera hypoleuca	absent	key species	bsent
Withania coagulans	absent	absent	rare

V.I. The Western Hajar Mountains

The flora of the Western Hajar mountains is one of the richest and most important floristic regions in Oman and in the Arabian Peninsula. A total of 298 vascular plant species (21% of the total flora of Oman) were recorded from the Wild Olive and Juniper woodlands above 1500 m in altitude, belonging to 214 genera and 73 families (Patzelt in press. b). 13 plant species found above 1500 m in the Western Hajar mountains are strictly endemic to Oman, and nine are near endemic or endemic to Arabia. The total of 22 range-restricted species represents 7.4% of the flora of the Western Hajar. An additional 33 species have been assessed as Threatened, Near Threatened, or Data Deficient but not range-restricted (Patzelt in press. b).

A. Sub-montane zone: *Euphorbia larica-Moringa peregrina* community (300–1500 m)

At an altitude of approximately 300 m, the xeromorphic open lowland *Acacia tortilis* woodland (see section IV.A) transitions into the sub-montane *Euphorbia larica-Moringa peregrina* shrubland (*Moringa peregrina* community type (Frey

& Kürschner 1986). This community includes at least 133 species, 9.4% of the total species of the country. The lower limit of this plant community is defined by the disappearance of many of the typical annual species including *Arnebia hispidissima* and *Anastatica hierochuntica*. The perennial shrubs *Ochradenus aucheri* and *Euphorbia larica* are common components. The upper limit for the *Euphorbia larica-Moringa peregrina* woodland ends with the disappearance of many of the key perennials and the appearance the Wild Olive (*Olea europaea* subsp. *cuspidata*) and *Sideroxylon mascatense*.

B. Montane zone: *Sideroxylon mascatense-Olea europaea* community (1500–2200 m)

The montane zone is dominated by an open hard-leaved sclerophyllous, evergreen woodland community characterised by the afromontane-Arabian Wild Olive (*Olea europaea* subsp. *cuspidata*), and the Arabian-Asian *Sideroxylon mascatense*. This plant community is restricted to the Western Hajar mountains; it occupies a maximum of 1077 km^2, representing 7.92% of the Western Hajar mountains land area and 0.34% only of the total country.

A total of 138 species have been recorded from this community (Patzelt 2009). Extratropical Irano-Turanian taxa and desert Saharo-Sindian taxa indicate the bi-seasonal type of climate. This community connects southern Arabia phytogeographically and floristically with Asia (Omani-Makranian distribution pattern). A phytosociological-chorological analysis of the community identifies its significance as species-rich, disjunct relict of a former continuous belt of xeromorphic sclerophyllous woodlands, ranging in the late Tertiary from palaeo-Africa via the southern Arabian Peninsula to southwest Asia.

The tree and shrub layers form an open structure, with the tree layer reaching a height of up to 8 m and the shrub layer up to 4 m in height; the tree cover ranges from 5–30% (Patzelt 2009). The Wild Olive woodlands are characterised by the presence of the Oman-endemics species *Polygala mascatense* and *Teucrium stocksianum* subsp. *stenophyllum*. The woodlands are unique to Oman and have their nearest links to similar woodlands in Pakistan and Afghanistan (Patzelt 2009).

C. High-montane Zone: *Teucrium mascatense-Juniperus seravschanica* community (2200–3000 m)

In the high-montane zone of Oman, along the plateau and on slopes with an inclination of up to c. 30% an evergreen needle-leaved cold-resistant woodland community is dominated by *Juniperus seravschanica* (Patzelt 2009).

Olea europaea subsp. *cuspidata*, *Sideroxylon mascatense* and the Oman-endemic *Ziziphus hajarensis* are key species, restricted to the refugium provided by the favourable climate at high altitudes (Image 1). The multi-layered vegetation structure is characterised by a number of endemic species, including *Teucrium*

Image 1: The Juniper woodlands are a high-montane evergreen plant community in the western Hajar mountains in Oman.

mascatense and *Stipa mandavillei.* The distinct endemic chasmophyte *Dionysia mira* is only found in a few locations.

A total of 67 species have been recorded from this community (Patzelt 2009). The juniper trees can reach up to 10 m in height and an age up to c. 1000 years (Sass-Klaassen et al. 2008). Most accompanying perennial species have a strict preference for relatively cold and wet conditions and are not found below 2200 m, including the Yellow Himalayan Honeysuckle *(Lonicera hypoleuca*) and the very rare *Cotoneaster nummularius*, which is restricted to the highest summit areas.

The *Teucrium mascatense-Juniperus seravschanica* community is unique to the Western Hajar but is closely related to juniper woodlands of the Central Asian mountains (Kürschner 1998). The juniper woodlands fall under the Irano-Turanian Regional Centre of Endemism which extends from the Anatolian plateau in Turkey to Central Asia and Pakistan to Oman. The flora and vegetation of the *Teucrium mascatense-Juniperus seravschanica* community are interpreted as the most southerly enclave of this rich south-west and central Asian phytochorion.

IV.II. The Eastern Hajar Mountains

At least 324 species occur in the Eastern Hajar, representing 23% of the total flora of the country. 30 range-restricted species are found in this mountains system (2.1%

of the total flora). 13 species are endemic to Oman, 2 species are near endemic and 13 species are regional endemic.

A. Colline and sub-montane zone: *Commiphora wightii-Grewia erythraea* shrubland (100–500 m)

The sub-montane zone is characterised by low perennial shrubs including *Commiphora wightii, Grewia erythraea,* and *Ochradenus aucheri*. The vegetation is dominated by grasses, herbs, and subshrubs; common species include *Heliotropium calcareum*, the near endemic *Lavandula subnuda* and the regional endemic *Pulicaria glutinosa* subsp. *glutinosa*.

B. Montane zone: transitional shrubland with *Rhus aucheri* (500–1200 m)

A xeromorphic mixed shrubland and herbaceous community characterise the montane zone. Common shrubs include the Oman endemic *Rhus aucheri*. At higher altitudes, the two *Helianthemum* species (*H. lippii* and *H. kahiricum*) become dominant species. The upper limit for this shrubland ends with the disappearance of many of the key perennials and the appearance the Arabian Almond (*Prunus arabica*).

C. High-montane zone: *Prunus arabica-Ceratonia oreothauma* steppe woodland community (1200–1850 m)

The high-montane zone is characterised by xeromorphic steppe woodlands dominated by the Irano-Turanian Arabian Almond (*Prunus arabica*); *Acacia gerarrdii* subsp. *negevensis, Ziziphus hajarensis* and the regional endemic *Ceratonia oreothauma* subsp. *oreothauma* are other key tree species. Typical dwarf shrubs include the endemic *Pycnocycla prostrata* and *Ephedra pachyclada*. Annual plants take advantage of the shade and increased moisture levels associated with the deep crevices and wadi systems carved into the landscape. Hardy ferns appear in the shaded cracks and crevices including *Onychium divaricatum, Cheilanthes vellea* and *Actinopteris semiflabellata*.

The *Prunus arabica-Ceratonia oreothauma* steppe woodlands are unique to Oman and have their nearest links to similar woodlands in Musandam and in the Zagros mountain arch in Iran (Frey & Probst 1986). The woodland in Oman is interpreted as the southernmost outlier of the Irano-Turanian steppe woodland vegetation, indicating a pre-Pleistocene migration route from the Zagros mountain arch into Arabia. Extratropical Irano-Turanian taxa reflect the close phytogeographic relationship to Central Asia. This community connects southern Arabia phytogeographically and floristically with Central Asia.

D. High-montane Zone: *Helianthemum kahiricum-Convolvulus acanthocladus* desert steppe community (1200–1850 m)

On the exposed summit plateaus, treeless steppe vegetation consisting of dwarf shrubs and grasses is found. *Helianthemum kahiricum, Echiochilon persicum*,

and the Irano-Turanian *Convolvulus acanthocladus* and *Ephedra pachyclada* are characteristic species. A few enigmatic bulb species are present in this community, including the Irano-Turanian *Dipcadi erythraea* and *Gagea* aff. *reticulata*, a recent new country record. A new record for Arabia is the Irano-Turanian *Withania coagulans* (Patzelt et al. 2014). The *Helianthemum kahiricum-Convolvulus acanthocladus* desert steppe has its nearest links to similar steppe vegetation in Musandam and in Zagros mountain arch in Iran (Frey & Probst 1986), representing a southernmost outlier of the Irano-Turanian desert steppe vegetation.

IV.III. The Musandam Mountains

At higher elevations, the flora and vegetation of Musandam are significantly different to the Western Hajar mountains further south, but show the same relationship to the Irano-Turanian desert steppe vegetation as the Eastern Hajar. The vegetation is characterised by many species which are restricted to Musandam within Oman, but also occur in the high plateau of central Iran.

Musandam (Oman territory only) is home to at least 394 plant taxa (28% of the national total). At least 94 species, representing 6.6% of the total flora of Oman are restricted to Musandam. This exemplifies the unique character of the flora of Musandam, which can be described as a key plant diversity area within Oman. The significant increase in species numbers recorded over the last few years is a direct function of sustained plant recording-field work, resulting in many new records for Musandam and/or Oman (Feulner 2011; Patzelt et al. 2014).

No species has yet been identified as strictly endemic to Musandam, but the area contains five plant species endemic to Oman, one near endemic species and nine species endemic to the Arabian Peninsula; 14 plant species are considered to be rare and threatened but not range-restricted (Patzelt in press. a). Three species have extremely restricted ranges and are only known from one or two locations including the endemic *Echinops atrox*, and the Irano-Turanian *Salvia mirzayanii* and *Thymelaea mesopotamica*. New records for Oman include *Hypocoum pendulum* and *Leptaleum filifolium,* first recorded in 2014 by Oman Botanic Garden.

A. Sub-montane and montane zone: *Pulicaria edmondsonii-Moringa peregrina* community (300–600 m)

At an altitude of approximately 300 m, the xeromorphic lowland *Acacia tortilis* woodland (see section IV.A) merges into the *Pulicaria edmondsonii-Moringa peregrina* open shrubland. This zone is closely related to the *Euphorbia larica-Moringa peregrina* community found in the Western Hajar (see section IV.A). The upper limit for the *Pulicaria-Moringa* shrubland is indicated by the appearance of trees and shrubs associated with the montane zone such as *Ficus johannis* and the Irano-Iranian *Astragalus fasciculifolius*.

B. Montane zone: *Convovulus acanthocladus* desert steppe community (600–1100 m)

The characteristic shrubs of the sub-montane zone disappear and montane species such as *Convovulus acanthocladus* and *Astragalus fasciculifolius* subsp. *arbusculinus* appear. A typical species of this zone is the regional endemic *Pulicaria edmondsonii.* The Arabian Almond (*Prunus arabica*) replaces the morphologically similar but ecologically different *Moringa peregrina* and *Ficus johannis* replaces *Ficus cordata* subsp. *salicifolia* (Feulner 2011). The upper limit for this zone is indicated by the appearance of species associated with higher elevations such as *Ephedra pachyclada* and *Artemisia sieberi*.

C. High-montane zone: *Artemisia sieberi-Ephedra pachyclada* desert steppe community (1100–2000 m)

The high-montane steppe vegetation includes elements from the central Iranian plateau (Frey & Probst 1986), and differs significantly from the higher elevation flora of the Western Hajar mountains, although the similarity to the flora of Iran is conspicuous. Examples of Irano-Turanian species common to Musandam and the high plateau of Central Iran include *Artemisia sieberi*, the very rare *Salvia mirzayanii*, *Ephedra pachyclada, Convolvulus acanthocladus* and *Cymbopogon jwarancusa*. This community has been called '*Artemisia* steppe' by Mandaville (1985). The *Artemisia sieberi-Ephedra pachyclada* desert steppe supports a rich diversity in annual plants, many of which are within Oman restricted to Musandam, including *Thymelaea mesopotamica* and *Pentanema divericatum*.

D. High-montane zone: *Astragalus fasciculifolius-Prunus arabica* steppe shrubland community (1200–2000 m)

The *Astragalus fasciculifolius-Prunus arabica* cold-resistant steppe shrubland in Musandam is interpreted as the southernmost outlier of the Irano-Turanian steppe woodland vegetation, indicating a former migration of these floristic elements from the Zagros mountain arch into southern Arabia. Examples of Irano-Turanian species include *Astragalus fasciculifolius* subsp. *arbusculinus* and the Arabian Almond (*Prunus arabica*). The steppe shrubland in Musandam can be interpreted as being part of disjunct belt of xeromorphic cold-deciduous woodland known from the high plateau of Central Iran. The *Astragalus fasciculifolius-Prunus arabica* steppe shrublands are interpreted as a relict of a former continuous belt of xeromorphic cold-resistant woodlands, ranging from Central Asia to the southern Arabian Peninsula.

E. Montane and high-montane zone: cliff faces, gorges and steep slopes (400–2000 m)

Steep cliff faces and gorges are found in many locations throughout the Musandam. In steep and cool north-facing cliffs above 1600 m, the endemic *Centaurea wen-*

delboi, the grass *Cymbopogon jwarancusa* subsp. *olivieri*, and the very rare and endangered Irano-Turanian *Salvia mirzayanii* can be found. On south-facing steep cliffs and slopes above 1400 m *Stipa mandevillei* and *Lactuca orientalis* characterise the vegetation. *Rosularia adenotricha*, a new record for Oman first recorded in 2014 by Oman Botanic Garden, is found in small rock cracks and crevices.

F. High-montane zone: *Ixilirion tataricum-Moraea sisyrynchium* bulb community (1200–1600 m)

In the high-montane zone, agricultural terraces were established centuries ago principally for the cultivation of winter wheat and barley (Feulner 2011). Today, some are still partially used, but many terraces have been abandoned in recent decades. These terraces are particularly rich in species; they represent a vegetation type which exists nowhere else in Oman.

Of significant botanical importance are highly ornate bulb species, including *Moraea sisyrinchium, Gladiolus italicum, Ixilirion tataricum*, *Bellevalia* sp. aff. *longipes*, and *Leopoldia longipes*. Four out of the five highly ornamental bulb species are seriously threatened (*Ixiolirion tataricum, Moraea sisyrynchium, Bellevalia* sp. aff. *longipes,* and *Leopoldia longipes*). Species which are restricted in their national distribution to the terraces include *Matricaria aurea, Aegilops kotschyii* and *Carduus pycnocephalus*.

VI. The mountains of southern Oman

The mountains of southern Oman (Dhofar) lie in the monsoon belt and for three months each year from mid-June to mid-September the area comes under the influence of the southwest monsoon, as part of a larger phenomenon called the Inter Tropical Convergence Zone (Bookhagen et al. 2005).

The area is an outstanding example of an island-like refugium and represents a fragile ecosystem unique on a global scale (Miller 1994, Kürschner et al. 2004, Hildebrandt & Eltahir 2006, Patzelt in press. a). The vegetation is dominated by a narrow band of deciduous vegetation skirting along the coastal mountains from southern Oman into eastern Yemen. The desert cloud oasis is among the most diverse ecosystems of the Arabian Peninsula (Miller 1994), and includes a large number of rare and endemic plant species, as well as endemic vegetation types. The escarpment cloud forest and associated habitats show a strong interdependence between the vegetation and the climatic system.

The interplay between topography and the monsoon profoundly influences precipitation quantity and distribution. During the monsoon, there is an upwelling of cold water off the coast which rapidly cools the moist winds to dew point, causing dense fog to form against the seaward-facing escarpments. Because of

the cloud cover, the temperature drops and relative humidity reaches 90–97%. The fog formation can extend up to 250 km along the escarpment and up to 50 km inland (Stanley-Price et al. 1988). As the low cloudbank moves inland, it cannot rise because of a temperature inversion created by the flow of warm dry air from the desert inland, limiting the vertical extent of the cloud cover. The cloud base varies from sea level upwards, averaging around 150 m; the cloud top varies between 600 and 1500 m.

This combination of topography and temperature inversion creates stable conditions for about three months, with persistent thick stratus clinging to the sea-exposed slopes of the mountains. The temperature rises again when the monsoon lifts in September.

Three seasons are identified in the monsoon-affected zone: (1) wet season – June to August; (2) transition season – September to November, and (3) dry season – December to May. During the wet season high rates of vegetative growth occur, creating a lush and green environment. The tree canopy gains additional water by intercepting cloud droplets, a phenomenon known as horizontal precipitation. During the transition season a lot of generative growth takes place as a result of the residual water stored in the soil, effectively doubling the length of the monsoon influence and most species come into flower and fruit. During the dry season, many trees shed their leaves and most plant species enter a dormant phase.

Jabal Dhofar is subdivided into Jabal Al Qamar (highest altitude c. 1500 m), Jabal Al Qara (c. 900 m), and Jabal Samhan (c. 1850 m). Jabal Al Qamar experiences a higher precipitation than the other two mountain ranges. The flora of Jabal Al Qamar alone consists of at least 515 vascular plant species, Jabal Al Qara houses at least 467 species and 377 species have so far been recorded from Jabal Samhan.

145 range-restricted species (endemics, near endemics and regional endemics) have been recorded from Dhofar (Patzelt in press. a), representing 10.3% of the total flora of the country.

Comparing the importance of the main vegetation types of all three mountain ranges shows an interesting pattern and reflects the different climatic conditions (Table 4).

Jabal Al Qamar and Jabal Al Qara are strongly influenced by the monsoon, whereas Jabal Samhan is a mostly barren limestone mountain massif, at the edge of a desert cloud forest ecosystem. A small western-most area of Jabal Samhan just falls under the influence of the summer monsoon, but the far-reaching summit plateaus are only affected by the cooler monsoon winds. Jabal Samhan's climate with its characteristic spatial and temporal variation has shaped the independent evolution of its flora. This has resulted in the description of the area as representing an own centre of endemism (see section 3), reflecting the distinctly different flora and vegetation.

Table 4: Absence/presence of the main vegetation types in the three mountain ranges of Dhofar (southern Oman).

	Jabal Al Qamar	Jabal Al Qara	Jabal Samhan
Acacia-Commiphora shrubland	present	present	dominant
Anogeissus dhofarica forest	dominant	dominant	very restricted
Themeda quadivalvis savannah	present	rare	absent
Olea-Maytenus woodland	dominant	absent	present
Euphorbia balsamifera cushion-shrub	dominant	dominant	very restricted
Euphorbia cactus community	present	absent	absent
Aloe dhufarensis shrubland	dominant	absent	absent
Dracaena serrulata community	dominant	absent	very restricted
Barleria samhanensis community	absent	absent	present
Boswellia sacra shrubland	dominant	dominant	dominant
Heliotropium community	dominant	dominant	ominant

The north-facing slopes and large wadi systems of all three mountain massifs are exposed and sun-baked and not affected by monsoon precipitation. They are subjected to high summer temperatures and receive intermittent rainfall or in some years, none at all. Most wadi systems are deeply incised canyons, often several hundred meters deep. Several permanent water systems are present.

The unique and endemic plant communities, including the *Anogeissus dhofarica* forest (Kürschner et al. 2004) and the *Themeda* tall-grass savannah (Patzelt 2011) are found exclusively in the monsoon-affected mountains of Dhofar and across the border in nearby Yemen. It is strongly suspected that most other plant communities described below are endemic as well. Work to describe, classify and rank these communities is currently on-going.

A. Planar to colline zone: drought-deciduous thorn woodlands and shrublands; *Acacia hamulosa-Commiphora gileadensis* community (0–200 m)

The *Acacia-Commiphora* open woodland and shrubland dominates the plains and lower mountain slopes on the seaward-facing slopes. *Commiphora kua* and *C. gileadensis*, *Acacia hamulosa*, *Acacia laeta* and the endemic *Jatropha dhofarica* are commonly found throughout this open woodland. Grasslands on the coastal plain were common in the past, but have today been more or less destroyed.

B. Planar to montane zone: drought-deciduous *Anogeissus dhofarica* forest (0–1000 m)

The drought-deciduous forest in Dhofar depends on persistent seasonal fog, representing a cloud forest under semi-arid conditions. The desert cloud ecosystem in Dhofar is a unique, fragile ecosystem surviving under conditions that are significantly warmer and dryer compared to cloud forests found elsewhere in the world. The water demand of the cloud forest is comparatively low, as incoming radiation and transpiration rates are suppressed during the monsoon. The long dry season means the forest exists at the very edge of its natural range.

The plant community has been described in 2004 (Kürschner et al. 2004). *Anogeissus dhofarica* is a relict species of the Tertiary and is a remnant of a former moist vegetation belt of palaeo-African origin (Kürschner 1998; Patzelt 2011), with close links to the flora of East Africa. At least 262 species are recorded from the *Anogeissus* forest (19% of the total flora), showing the extreme species richness of this plant community. The forest supports an exceptionally rich understory, characterised by many different life forms, such as herbs, shrubs, lianas, bulbs, annuals and grasses, many of which are endemic (Image 2). Main species in the tree and shrub layer include the near endemics *Maytenus dhofarensis, Blepharis dhofarensis* and *Blepharispermum hirtum*.

C. Montane zone: Annual *Themeda quadivalvis* tall-grass savannah (600–900 m)

Themeda quadrivalvis tall-grass savannah replaces the *Anogeissus* forest on plateaus at middle altitudes. The tall-grass savannah forms a 3 km to 5 km wide belt on the gentle seaward-facing gentle mountain slopes (Patzelt 2011); the grasslands are interpreted as a result from anthropogenic activities in recent centuries to millennia. Characteristic species of this plant community are the annual grasses *Themeda quadrivalvis, Setaria pumila* and *Apluda mutica*, and the wild okra (*Abelmoschus manihot*). The community is rich in species, with 112 species being recorded (8% of the total flora of the country) (Patzelt 2011). The association is interpreted as an impoverished easternmost outlier of the East African savannah.

D. Montane zone: Drought-deciduous sclerophyllous *Olea europaea-Maytenus dhofarense* woodland community (900–1200 m)

At higher altitudes, the *Olea europaea-Maytenus dhofarense* community exists as a separate belt above the *Anogeissus* forest. This vegetation zone receives slightly less horizontal precipitation than the *Anogeissus* forest. Characteristic tree species are the near endemic *Maytenus dhofarica* and the Wild Olive (*Olea europaea* subsp. *cupidata*). *Anogeissus* trees occur as isolated specimens, but do not form a continuous canopy cover.

Image 2: The *Anogeissus dhofarica* forest is found in a narrow band on the seafacing-mountains. It has one of the highest plant species diversities of all plant communities of the Arabian Peninsula.

This belt of sclerophyllous, drought-deciduous woodland is also known from tropical East Africa, and from the southwestern mountains of Saudi-Arabia and Yemen and can be been interpreted as relict vegetation of the Tertiary semi-deciduous xerotropical forest belt, formerly ranging from Africa to Asia.

E. Montane zone: drought-deciduous *Euphorbia balsamifera-Commiphora foliacea* cushion shrub community (800–1300 m)

This succulent community, characterised by the Balsam Spurge (*Euphorbia balsamifera* subsp. *adenensis*) and stunted Myrrh species (*Commiphora kua, C. foliacea*, and *C. gileadensis*), is locally abundant in areas with gentle slopes, shallow soils and rocky surfaces at higher altitudes. The habitat is affected by the cool monsoon wind and fog, although it is beyond the reach of the continuous dense fog.

Characteristic species are the stem-succulents *Monolluma quadrangula* (regional endemic), *Orbea luntii* (near endemic), and *Echidnopsis scutellata* subsp. *dhofarensis* (endemic). This endemic plant community comprises at least 118 species (8.3% of the total flora). The *Euphorbia balsamifera-Commiphora foliacea* community is closely related to an *Euphorbia balsamifera* community described

from the mountains of Yemen (Deil & Müller-Hohenstein 1984). The area falls is included in the Somali-Masai regional centre of endemism, and most species represent this close link between East Africa and the mountains of southern Arabia.

F. High-montane zone: drought-deciduous *Cocculus balfourii-Euphorbia cactus* cliff community (1200–1600 m)

The *Cocculus balfourii-Euphorbia cactus* community is locally abundant on exposed high altitude south-facing cliffs and steep slopes. This community benefits from the cool winds and occasional fogs by the monsoon, although it is outside of the monsoon precipitation zone. Characteristic species are the regional endemic *Cocculus balfourii* and *Euphorbia cactus*. This community is closely related to the *Euphorbia cactus* community described from the mountains of Yemen (Deil & Müller-Hohenstein1984).

G. High-montane zone: *Seddera glomerata-Aloe dhufarensis* succulent community (1200–1500 m)

On high plateau areas, the landscape is dominated by an endemic *Seddera glomerata-Aloe dhufarensis* shrubland. The high plateau vegetation supports annual species and many grasses and small perennial dwarf shrubs, including the endemics *Portulaca dhofarica*, *Pulicaria argyrophyllum* subsp. *oligophylla*, and *Seddera glomerata* subsp. *glomerata*.

The orientation and spatial distribution of *Aloe dhufarensis* are striking: The plants are regularly spaced with approximately 1.5 m between each plant. They are distinctly oriented towards the south, with the leaf rosette open to the cloud and fog of the monsoon, thus ensuring maximum moisture capture.

This endemic plant community comprises at least 70 species (c. 5% of the total flora), including eight endemic and near endemic species. This community shows strong affinities to xerotropical succulent communities described from Yemen and Saudi Arabia (Deil & Al Gifri 1998), being vicariant to the *Seddera glomerata-Aloe dhufarensis* in Oman.

H. High-montane zone: xeromorphic *Euphorbia schimperi-Dracaena serrulata* rock community (800–1200 m)

The Arabian Dragon Tree (*Dracaena serrulata*), a stunning regional endemic species, is an unusual and conspicuous species found at higher altitudes and restricted largely to the high dry plateaus at the leeward side of the monsoon-affected mountains (Image 3). The community receives some benefit from the monsoon clouds and cool winds, but is beyond the consistent solid cloud cover. Vicariant communities with *Dracaena* species are found in Djibouti, Somalia, the Canary Islands and Soqotra (Deil & Al Gifri 1998).

Image 3: *Dracaena serrulata* is a flagship species, found on steep slopes on the sea-facing mountains.

Characteristic species include the endemic *Lavandula dhofarensis* subsp. *ayunensis* and the rare orchid *Eulophia petersii*. The plant community comprises at least 100 species (c. 7% of the total flora), including many endemic and near endemic species.

Worryingly, the *Dracaena serrulata* has shown serious signs of dieback in recent years. The reasons for this are uncertain, but may be related to climate change and a decrease in cloud cover. This species is distributed in fragmented sub-populations which appear only to contain adult individuals with little sign of active regeneration. Active research and conservation management is urgently required to safeguard this attractive species from extinction in the wild.

I. High-montane zone: xeromorphic *Salvia hillcoatiae-Lavandula hasikensis* community (1300–1600 m)

Plant endemism in Jabal Samhan is particularly high, especially on the high plateau and in adjacent wadi systems (Knees et al. 2007). Species such as *Pulicaria samhanensis*, *Barleria samhanensis*, *Salvia hillcoatiae* and *Lavandula hasikensis* are all endemics restricted to Jabal Samhan. This section of the high plateau is at the fringe of the monsoon-affected area. It benefits from occasional cool winds, but

does not experience regular precipitation during the monsoon period. The presence of these plant species, alongside with other endemics supports the hypothesis that the high plateau of Jabal Samhan forms a distinct floristic unit, containing a number of very restricted endemic plant species and being significantly different to any other vegetation unit (see section 3).

J. Montane and high-montane zone: *Tetraena decumbens-Boswellia sacra* community (500–1200 m)

The Frankincense tree (*Boswellia sacra*) is common in the large wadi systems and on the wadi slopes beyond the reach of the monsoon precipitation (Image 4). Sparse vegetation cover is characteristic of this community; the dominant life-forms are small perennial xerophytic shrubs and grasses. However, in shallow depressions and on wadi banks and slopes, denser vegetation forms including *Tetraena decumbens*, the Dhofar-endemic *Trichodesma cinereum*, the rare *Euphorbia orbiculifolia*, and the near endemic *Ochradenus giffrii*.

K. Sub-montane and montane zone: *Launaea castanosperma-Heliotropium bacciferum* community (300–1000 m)

On wadis sides, on slopes, and on the dry exposed plateaus, a desert dwarf shrubland with perennials and dwarf shrubs including the near endemic *Launaea castanosperma* is present. The plateaus and slopes often seem almost devoid of plants, however after rain, annual plants such as the bright yellow-flowered *Diplotaxis harra* are abundant.

VII. Wadis

A number of large wadis, occasionally with permanent water bodies carve their way through the mountains. The wadis tend to be very ‘flashy’ in that they respond rapidly to the erratic rainfall, so that water-levels and flow velocity vary considerably and stream velocity is very high during the occasional flood events. This creates an unstable ecosystem with inherent challenges for persistent plant growth. According to the interaction of a range of factors including frequency and intensity of water flow, stream velocity, depth of groundwater, grain size of the sediments, and the altitude, and size of water catchment area, different wadi vegetation types can be recognised.

The wadi slopes are often cut into the bare rock, the wadi bottom is covered with boulders. At most times, the major part of the wadi bottom is dry and only a number of pools or smaller runnels of water remain.

A. Planar and colline zone: extratropical wadis in northern Oman (0–300 m)
In deeply incised often canyon-like wadis at lower altitude in northern Oman a community characterised by the presence of *Nerium oleander* is present (Deil &

Image 4: The frankincense is without doubt the most famous plant of Dhofar and once was of vital economic importance.

Müller-Hohenstein 1996). A number of species grow along the margins in shallow water, including *Arundo donax*, *Nerium oleander, Salix acmophylla*, and tall grasses (*Saccharum kajkaiense* , *S. ravennae* and *S. griffithii*). The phreatophytes *Prosopis cineraria, Ziziphus spina-christi* and *Ficus cordata* subsp. *salicifolia* are common. This wadi type belongs to the extratropical type; they are recorded from the whole saharo-arabian and nubo-sindian region (Deil & Al Gifri 1998).

B. Planar and colline zone: tropical wadis in southern Oman (0–300 m)

Wadis in the monsoon affected area in Dhofar shelter gallery forests with *Ficus vasta, F. sycomorus, F. lutea*, and *Tamarindus indica*. They are usually found within the *Anogeissus dhofarica* forest. Climbers and lianas such as *Cissus quadrangularis, Luffa acutangula*, and *Cucumis sativus* are commonly associated.

C. Herbaceous wadi and irrigation channel communities (0–2600 m)

Most herbaceous wadi plants in Oman are characterised by species which are able to tolerate drought; they are found on damp ground, but may occasionally undergo dry periods. Characteristic species include *Bacopa monnieri, Phyla nodiflora, Pentadon pentandrus* and *Fimbristylis* species.

Water-dependent plants are also typically found in artificial habitats such as irrigated land, damp areas around settlements and along the irrigation channels. The "aflaj" (singular "falaj") irrigation system in northern Oman represents an important habitat in areas where there are few natural water bodies. Especially around leaks of old and less-well maintained water channels plants dependant on water are present.

D. Seasonally inundated depressions

Seasonally inundated depressions are a particularly important habitat for local wetland plant species. This habitat typically supports species capable of surviving as annuals, but which persist during dry periods in the seed-bank, including a number of rare or local taxa, such as *Bergia polyantha*, which was first recorded from Oman in 2014 (Patzelt et al. 2014).

E. Runnels, ravines, gullies and wadis within shrublands, woodlands and forests

In runnels, small ravines, and deeply incised wadis the adjacent vegetation is often denser and species abundance is higher. This is typical for many arid countries, as runnels, gullies and wadis receive run-off water and sediments are accumulated through water and wind, resulting in slightly deeper soil layers, thus supporting higher cover and abundance of species. The wadi communities are closely associated to the surrounding vegetation, and may in many cases represent an enhanced representation of the adjoining vegetation.

VIII. Aquatic ecosystems in springs and pools

While the Arabian region mainly comprises of dry, arid habitats, there are also several permanent freshwater systems; they are often in stark contrast to the surrounding landscapes (Patzelt et al. in press.). The small number and scale of permanent water bodies means that the country supports only a few obligate aquatic species. Those which do occur are typically species with a wide global distribution such as duckweeds (*Lemna* species), naiads (*Najas* species), and pondweeds (*Potamogeton* species).

Groups of *Bolboschoenus maritimus, Typha domingensis* and *Juncus rigidus* are a familiar feature in this habitat.

IX. Agro-biodiversity in Oasis systems

The Hajar mountains in northern Oman exemplify a unique form of terraced agriculture in spring-fed oases that has existed for millennia. Archaeological evidence shows that the mountains oases have existed since at least 1100 BC

Image 5: The oasis settlements in the Western Hajar mountains are thousands of years old; Cultivation of temperate crop trees such as Apricot and annual crops with endemic wheat landraces is sustained by a complex and sophisticated irrigation system.

(Nagieb et al. 2004). A wide variety of crops and fruit trees is still cultivated in the traditional subsistence-based manner. The terraces are typically constructed on very steep slopes, and the width is sometimes limited to one or two meters due to the dramatic topography (Image 5). Due to the arid climate, these agricultural terraces rely heavily upon an ancient irrigation system. The spring-based irrigation channel system (Arabic: falaj, plural 'aflaj') provides an abundant and reliable flow of water from mountain springs. While recent studies have identified 2430 oases in northern Oman, only approximately 3% of them are mountain oases (Lüdeling & Bürkert 2009).

The most important tree in cultivation at low altitude is the date palm, other species include mango trees, and various citrus trees. Above 1500 m altitude, the main perennial crops are Walnut, Almond, Peach, Apricot, Pomegranate, and Damask Rose. Typical annual crops and cereals grown on the mountain terraces include Garlic, Onion and endemic Wheat landraces (Gebauer et al. 2007).

The intensive irrigation allows surprisingly diverse and species-rich weed communities. A floristic inventory of the weed vegetation on terraces above 1500 m altitude revealed the presence of at least 77 species in three oasis systems only

(Patzelt 2009). The weed communities are characterised by typical temperate and Mediterranean weeds. Due to their remote location, the mountain oasis settlements of the Hajar Mountains retained their traditional crop management systems virtually unchanged for millennia. No pesticides or herbicides were used for the control of weeds, and crops are still mainly fertilised with animal manure, minerals, and ashes. Rapid modernisation is now increasingly leading to the abandonment of terraces. The complex irrigation system, traditional agricultural techniques, and traditional knowledge about plants and their uses are all in danger of being lost.

X. Ruderal Vegetation

Development, habitation, cultivation and grazing have considerately altered the natural vegetation. Largely as a result of these activities numerous areas are destroyed or at least seriously degraded and reduced in species numbers and diversity. In many cases, particularly adjacent to human habitation weedy, ruderal plants, such as the poisonous Sodom's Apple (*Calotropis procera*) and other unpalatable species have become the dominant species. Research into the ruderal vegetation of Oman has not yet been conducted.

XI. Conservation Aspects

Many of the habitats of Oman form part of fragile ecosystems and are highly sensitive to disturbance and very slow to regenerate. Extended areas of the unique vegetation of the country have today been over-exploited and destroyed or are suffering from habitat degradation. In the past, traditional land-use management practices played a pivotal role in protection against overexploitation. Today, many traditional land uses are either modified or completely abandoned. The most serious change is the dramatic increase in livestock numbers, which has resulted in extensive overgrazing.Overgrazing is the most serious threat to the plants of Oman and also is one of the main factors contributing to the lack of regeneration of many key tree species, e.g. *Ceratonia oreothauma*, *Juniperus seravschanica*, and *Dracaena serrulata*. Urban sprawl and infrastructure development are equally putting pressure on many habitats.

Climate change is also assumed to be increasingly affecting high altitude vegetation. Temperatures in Oman have increased significantly in the last two to three decades, minimum temperatures increases reached up to 3–6°C from 1980 to 2008 (Alsarmi & Washington 2011). These data underscore the concerns about climate change effects on flora and vegetation of the Arabian Peninsula.

Only small areas of the country are under effective protection with many important ecosystems wholly unprotected. The designation of a network of representative

protected areas with appropriate active management systems in place should be a matter of priority for *in situ* conservation, while *ex situ* conservation is given increasing national emphasis. The Oman Botanic Garden, currently under construction, holds the largest documented collection of Arabian plants in the world (Patzelt et al. 2008; Patzelt et al. 2009). The garden has the unique aim of propagating and displaying the complete indigenous flora of Oman, and aims to address the urgent need for conservation solutions to the biodiversity crisis. Actively addressing targets of the GSPC (Global Strategy for Plant Conservation), the Oman Botanic Garden represents a new model for botanic gardens in the 21st century and is a ground-breaking initiative of *ex situ* conservation in Arabia.

XII. Summary

The flora and vegetation of Oman are exceptionally rich in a regional context, with high levels of endemism in many plant communities. Whereas very good progress of the floristic knowledge and the understanding of the patterns of phytogeography and plant endemism have been achieved, much of the vegetation is yet to be described in detail. This contribution tries to provide a basic overview over the main vegetation types, as a prerequisite for further ecological and phytogeographical studies and conservation management activities.

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